**BIOMECHANICS IN IMPLANTS: - A CRITICAL OPINION**

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**ABSTRACT: -** Dental implants are considered the best treatment options for replacement of missing teeth due to high survival rates and diverse applications. However, not all dental implant therapies are successful and some fail due to various biological and or / mechanical factors. The objective of this study was to systematically review primary studies that focus on the biomechanical properties of dental implants and to emphasize upon all the factors that play a role in the survival rates of the implant.

**KEYWORDS: -** Biomechanics, Oral implants, Oral prosthesis, loading.

**INTRODUCTION:-**

Applied mechanics, most notably thermodynamics and mechanical engineering disciplines like fluid mechanics and solid mechanics, play prominent roles in the study of Biomechanics. Biomechanics includes bio-engineering, research and analysis of the mechanics of living organisms and the application of engineering principles to and from biological systems (1). There are two different types of aspect to biomechanics. There is Reactive biomechanics and Therapeutic biomechanics. Therapeutic biomechanics is a process of remediating each biomechanical factor in order to diminish implant overloading (2

Reactive biomechanics includes any type of implant prosthesis that increases the implant stress loading ability which simply translates into more stress on the implant resulting in better remodeling of bone around implant and better Osseo integration(4).

**INTERELATED FACTORS:-**

There are many inter-related factors which contribute to the success of Implants which should be duly analyzed and accordingly diagnosis and treatment planning should be developed in order to maintain a state of equilibrium. The factors that determine the proper functional ability of the prosthesis is biomechanics, occlusal forces and esthetics (5).

Force is any application of energy, either internal or external to a structure, that which initiates, changes or arrests motion. There are many related factors of force like magnitude, duration, type, direction and magnification (7). Magnitude varies from location to location inside patient’s mouth and also depending upon prosthesis type.A table regarding magnitude of force depending upon different anatomic region and state of dentition is depicted below as stated by various authors.

Craig (1980)

Molar - 390-880N

Canine - 453 N

Incisor – 223 N

Parafunction – 1000 psi

Colaizzi, (1984)-Complete Denture – 77-196 N

Carlsson & Haraldson , (1985-)Denture with Implant – 48-412 N

Duration of the force also plays a impact with mastication force of about 9 minutes per day produces a force of 20 to 30 psi while swallowing about 20 minutes per day 3 to 5 psi(8). There are also many forces magnifying factor that increases the torque on implant prosthesis like extreme angulation, cantilevers, and crown height, Parafunction and bone density. A 1 mm increase in the implant crown height will cause 20 percent increase in torque (9).

Torque is a multiple of force and distance where in case of natural tooth the distance is measured from height of contour of tooth to the apical one third of the natural tooth. In case of Implants the distance is measured from height of contour to the first third screw level (10).

Compressive forces tend to maintain the integrity of bone implant interface and are also best accommodated by a complete implant prosthesis system. Tensile forces pull the object apart and tend to distract and disrupt such an interface (12). Shear forces are most destructive to implant and can causes sliding of the implants. Shear forces also tend to distract or disrupt bone to implant surface.

Forces falling on natural teeth are in turn transmitted to the periodontal ligament which causes flexion in the crestal bone resulting in even distribution of the force. However in case of implants which is a rigid, fixed and stiff structure, the forces concentrates first three thread level of the implant screw resulting in crestal bone loss and even peri-implantitis(13). Osseo integrated implants have potential as a firm osseous anchorage and also resist continuos horizontal forces of at least 5 Newton (about 510 gms) during a period of several months. Dental Implants which are successful also shows an average of 0.1 mm of average bone loss after first year. It is also observed that there is mean loss of 0.1 mm to 0.13 mm per year after first year of implant prosthesis functions (14).

**Differential Mobility:-**

There is a qualitative difference between the flexure of the periodontal ligament of the natural tooth and the stiffness of the Osseo integrated dental implant. The amount of micro movement is the major difference between natural tooth and Dental implant. A natural tooth with good bone will move laterally approximately 0.5 mm measured occlusally. A Dental Implant can move laterally 0.1 mm or less laterally measured occlusally. A table below depicts the differences between the natural tooth and Dental Implant (15).

 **Differences between a Natural tooth and Dental Implant**

 **Natural tooth**  **Dental Implant**

1. Flexion of Periodontal ligament Rigidly Fixed-Stiff
2. Even force distribution Concentration of force crestal bone
3. 0.5 µm movement laterally 0.1 µm movement laterally
4. Shock absorber ability in PDL Rigid
5. Reduces the magnitude of stress Increases the magnitude stress
6. Occlusal trauma with signs of No such warning signs but can

Cold sensitivity, wear facets, pits result in bone micro-fracture

drift away & mobility.

1. Elastic modulus is similar 5 to 10 times different then bone therefore

to bone. Stress concentration is at the crestal bone.

1. Surrounding bone is formed bone formation is rapid and intense

during childhood during Osseo-integration.

1. Lateral movement if exerted is lateral movement if exerted dissipated to

Dissipated to the apex crestal bone.

**Forces acting on the Implants:-**

There are various types of forces falling of the implants like normal occlusal loading of implants and parafunctional habits. Passive loading of implant is caused by mandibular flexure, contact with first stage cover screw and second stage permucosal extension (16). There are also peri-oral forces and non-passive prosthesis. Out of which the traumatic forces or the forces which cause implant overloading are non-passive forces, parafunctional habits, initial contact during maximum intercuspation and labial stresses generated during eccentric movement. Therefore, it is important to eliminate posterior contact during protrusion and lateral excursion. Implant prosthesis should only come in contact during maximum intercuspation to avoid lateral destructive forces on the implant which may eventually cause failure of the prosthesis (17).

 **Force distribution in the multiple Implant prosthesis:-**

Natural tooth have periodontal ligament which are elastic fibers attached to tooth in different angulations and help in dissipating forces and thus they act as shock absorbers. Implants are stiff when Osseo integrated and there is no force distribution and force only concentrates at the crestal bone (18).

There is another school of thought known as force distribution in the combined prosthesis where the prosthesis is supported by natural teeth’s and implants. In these types of prosthesis the mode of attachment is stiff and flexible(20). Flexible attachment is mostly preferred in the form of internal attachment embedded inside the crowns of the abutment tooth and implant abutment and stiff prosthesis is preferred in cases when implants are the terminal abutment with only centric contacts and no eccentric contacts.

Flexible attachment is in the form of female attachment in the tooth supported prosthesis and as a stiff attachment (screw retained) implant prosthesis which results in flexion but has no deleterious effect on the integrity of the prosthesis.

In case if the stiff attachment is preferred the crown is cemented on to the tooth with a permanent cement while the implant supported retainer is cemented with a temporary cement which tends to loosen if and when occlusal load both centric and eccentric fall on it, making retrievability easier and further corrections and cementation more practical.

**Diagnostic factors in Combined Prosthesis:-**

Standard prosthesis design for combined prosthesis provides for an internal attachment placed in the distal part of the natural tooth. This will compensate for the differential mobility between an apically flexible tooth and an rigid implant prosthesis. Attaching a rigid implant with a apically flexible natural tooth may cause loss of the designed prosthesis. Even increasing the lever arm increases the torque on the prosthesis which increases the chances of destruction of the prosthesis. Recommended prosthesis design dictates that there should be one cantilever pontic in each segment which prevents drifting apart of the segment and also decreases the torque and thereby prevents the failure of the prosthesis (23).

**Four clinical variant with Implant loading:-**

The four clinical variants in implants can be classified into Cuspal inclination, Impact inclination, Horizontal implant offset and vertical / apical implant offset.

1. Cuspal inclination: - Stresses on the implant and implant/abutment interface increased with increasing cusp inclination, and stresses on the cortical bone decreases with increasing cusp inclination. Increase in 10 degrees of Cuspal inclination results in 30 percent increase in torque forces.
2. Impact inclination:- Increase in 10 degrees causes increase in 5 percent torque.

1. Horizontal Implant off set:- there are some anatomical restrictions in which implants are not possible to be inserted in their conventional configuration. Offset placement of Implants in relation to the prosthetic unit could be a treatment solution. It can be safely concluded that the offset placement of a single dental implant does not offer biomechanical advantages regarding reducing stress concentration over the in-line implant configuration. It is suggested that the amount of offset should be as minimum as possible. Increase in 1 mm of horizontal implant offset increases the torque to around 15 percent (28).
2. Apical Implant offset: - it is similar to the horizontal implant offset but is in vertical direction where in increase of 1 mm causes increase in 5 percent of the torque.

A concept of staggered implant offset was introduced where in there is staggered buccal and lingual offset placement of implants which creates a tripod effect and helps in compensating for the torque forces falling on the prosthesis (30). In order to achieve this Implants are placed 1.5 mm buccal and lingual from the center line to achieve tripodism (31).

It was found that a palatal offset increases the torque by 24 percent while a buccal offset, in maxilla decreases the torque by 24 percent. Therefore, it is preferred to keep the buccal offset in the maxilla in order to reduce the torque (33). Placement of the implant in the posterior region if very important as posteriors is the active zone for the occlusal loading on to implants (34). Accordingly the occlusal forces should fall as much parallel to the long axis of the implants as much as possible.

**Therapeutic Biomechanics:-**

A new approach called therapeutic biomechanics that uses 5 possible corrective procedures that can be used in conjunction with each other to reduce implant loading. These approach includes (i) Cross occlusion ;(ii) the head of the implant should be placed as close to the midline of the restorations as possible;(iii) angled or custom reangulated abutment ;(iv) Shallow cusp inclines and (v) modified centric occlusal anatomy(36).

1. Cross Occlusion:- Changing the bucco-lingual relation of the implant vis a vis opposing teeth , helps in reducing the horizontal implant offset and thereby significantly helps in reducing torque.

1. Decrease in Cuspal Inclination:- By decreasing the Cuspal inclination it reduces the distance between implant and resultant line of force.
2. Implant position:- Keeping the head of the implant as close to the Centre line of restoration helps in reducing the horizontal offset and there by helps in 5% reduction in the torque.
3. Modified centric occlusal anatomy: - The standard occlusal anatomy where in the cusp inclines meet in a central groove and the cusps causes buccal and lingual axis line of forces. There is a physiologic variation in centric relation of 0.4 mm as per records and a lateral shift in the centric occlusion will result in buccally and lingually inclined resultant line of forces. By modifying the occlusal anatomy by shallowing the fossa helps in bringing the vertical line of forces within the expected range of physiological variation.
4. Anterior vertical overlap: - Steep vertical overlap in the anterior region causes extreme torque and thereby failure of the prosthesis, however reducing the steep vertical overlap reduces the torque.

**Biomechanics and resorption pattern:-**

Posterior mandible bone resorbs along the root inclination and therefore bone resorbs lingually so if there is lingual position of the restoration and buccal implant placement then there is increased torque which may cause failure of the implant and the therefore the restoration(42).

Therapeutic biomechanics can be done by reducing cusp inclination and putting the implant head close to the center line of restoration and angulated abutment should be parallel.

In posterior maxilla there is lot of problems associated with restricted maxilla, location of sinus, buccal cortical plate fracture and unfavorable mechanics.

 According to the Therapeutic biomechanics you can reduce Cuspal inclination and head of implant should be close to the center of restoration, using an angulated abutment or a customized abutment or cross occlusion can be given in order to reduce torque forces (46). In case of anterior maxilla esthetics is paramount along with a labial proclination of the maxilla resulting in steep vertical overlap of the anterior teeth which causes increased torque. Therefore here a lingual horizontal stop can be given to redirect the forces as vertically as possible along with angulated abutment and implant head movement closer to the center of rotation to reduce the horizontal offset (47).

**Complete Edentulism and Biomechanics:-**

Screw loosening can be avoided in a patient who is being restored by using implants by placing the Implant across and around the arch. Cross splinting which occurs by placement of the Implant across and around the arch reduces the lateral and vertical forces and adds to tripodism which provides excellent resistance to the bending (49).

**Wider Implants:-**

These implants were developed by Dr. Burton Langer and they have advantages in terms of increased surface area, placement in cases where limited bone height is there. Wider implant also plays an important role when there is a failure of standard size implant (50). Also when a wider implant is placed it can cause tighter joints and it increases overall strength of the prosthesis.

**Bone Density and Biomechanics:-**

Bone density increases the strength of the implant and as a result the overall integrity of the prosthesis increases. Bone density also increases the amount of bone contact with the implant and also helps in better distribution and dissipation of force. An FEM study about the different stress contour of the bone and gave the classification for different bone density as below(51):-

**D 1:-** Crestal stress and lesser magnitude

**D 2:-** Greater crestal stress along the implant body

**D 3:-** Greater stress transmitted apically.

**D 4:-** Greatest stress transmitted farthest apically.

**Bone Density and treatment plan modifier:-**

There are several factors which affect and augment bone density and helps in modifying the treatment plan as mentioned below(52):-

1. **Prosthetic factors:-** As the density of the bone decreases the biomechanical load should also decrease significantly. There are several methods by which we can reduce the load like shortening the cantilever length and narrowing down the occlusal table. It is also advised to reduce the offset load to the minimum and if the patient is wearing a removable prosthesis then removing it at night can reduce the unnecessary forces on the basal tissues. Using an RP-5 prosthesis is advisable as forces are shared by soft tissues. Allowing for the forces to be transmitted along the long axis of implant also helps in reducing the biomechanical load and reducing stress.
2. **Implant number:-** Increasing the number of implant helps in reducing the load as it helps in distributing the load over a wide area(snow shoe effect) and helps in increasing the functional load capacity.
3. **Implant macro geometry:-** In a D 1 bone an increase in length by 10mm, in a D-2 bone by 12mm and in a D -3 bone 14mm length with a V shaped thread screw is preferred. Generally it is believed that as the bone density quality increases the length of the implant should increase if not impeded by any important anatomical site of pathology.
4. **Increase in the width of the Implant:-**Increase in the width help in increasing the surface area of the implant bone integration. A 1 mm increase can help in increasing about 30% increase in the surface area of the implant bone contact. Therefore in D 3 & D 4 bone the placement of the wider implant is preferred.
5. **Implant design:-** Smooth cylindrical implant shows a lot of shear forces at the interface where as an threaded titanium implant exhibit the best biomechanical ability along with biocompatibility and corrosion resistance.
6. **Surface coating of the Implant:-** Various types of coating’s like hydroxyapatite coating’s along with sandblasting helps in increasing the surface area of the implant and also helps in increasing the bone-implant Osseo-integration.
7. **Progressive loading:-** The concept of progressive loading, advocated gradual increase in the occlusal load separated by an adequate time interval to allow for the bone to accommodate. Softer bone requires increase in the progressive loading time period. This protocol includes time, diet, occlusal contacts and prosthesis design.
8. **Time:** - two surgical appointments between initial implant placement and stage 2 recovery may vary on density. For a D-1 bone about 4 months’ time is required while for D-2 around 5 months is required. For D-3 bone around 6 months is given for osseo-integration while for D-4 bone around 8 months is required.
9. **Diet :-** The loading after implant placement is to be restricted by means of diet. Initially the pressure is to be limited to soft diet of around 10 pounds while after early delivery of the prosthesis the diet is to be restricted to around 21 pounds only.
10. **Prosthesis Design: -** Prosthesis design is a means of reducing the forces and helping in increasing the osseo-integration of the implant. During the first transitional phase there should be no occlusal contact and no cantilever should be given. During the second transitional phase occlusal contact can be given but no cantilever is allowed. In final restoration however a fine occlusal table along with slight cantilevering is permissible.

 **Cantilever prosthesis and Biomechanics:-**

Cantilever prosthesis results in greater torque with distal abutment as the fulcrum which can be compared to the Class I lever arm. Cantilever prosthesis extended anteriorly results in reduced amount of forces then compared to a posterior cantilever which exerts excessive amount of force (53). Cantilevering an implant prosthetics depends upon stress factors like Parafunction, crown height, Impact width and Implant number.

**Cantilever in fixed partial denture: -** When cantilever is given in an implant supported fixed partial denture, then a sufficient bone height should exist to place longer implant. Contact should be avoided on central incisors during protrusion, labial excursions and maximum intercuspation. Group function occlusal scheme should be provided in such prosthesis to avoid eccentric forces falling on them during lateral movement. Loading on the canine is to be avoided and lateral guidance to be central and lateral incisor. If two implants are supporting a first molar and second premolar with first premolar being a cantilever then active cusp can be eliminated.

**Mandibular Flexure:** - Mandible moves towards midline on opening because of the action of the external pterygoid muscle on the ramus of the mandible. Medial movement of the mandible occurs distal to the mental foramen and increases as it approaches ramus. It was also found that movement of the mandible is about 0.8mm in the 1st molar region and it increases to about 1.5 mm in the ramus area. When flexion of the mandible happens an implant placed in arch flexes to about 0.1 mm while a natural teeth flexes around 0.5 mm. This loss of flexion of the implant results in bone loss around the implant and manifests in loss of implant fixation and material fracture of the implant.

**Fatigue failure: -** An implant in the mouth is almost always under dynamic cyclic loading which can result in failure of the implant in a way of cyclic loading. An ability of the implant to resist fatigue failure depends on Biomaterial, geometry, force magnitude and number of cycles.

1. Biomaterial: - Stress level below which an implant biomaterial can be loaded indefinitely is referred as endurance limit. Titanium alloy exhibits high endurance limit.
2. Implant geometry: - It helps in resisting the bending and torsional load, which is related to metal thickness. Increasing the metal thickness two times makes the prosthesis sixteen times stronger.
3. Force magnitude: - Arch position in the mouth determines the force magnitude. The force magnitude is higher in the posteriors and lower in the anteriors. Force magnitude can also be eliminated by reducing torque and increasing the surface area of the prosthetic design.
4. Number of loading cycles: - Loading cycles should be reduced and an effort should be made to eliminate parafunctional habit. Also cyclic loading can be reduced by decreasing the occlusal contacts of the implant prosthesis.

 **Implant design and biomechanics:-**

Titanium alloys present the greatest strength of all the designated implant materials. Smooth sided cylindrical implants are subjected to shear forces. Smooth sided tapered implants places extreme compressive load at the interface (54). If the taper is increased then it increases the compressive load delivery and therefore the taper cannot be increased for more than 30 degrees. Increase in the implant width increases the functional area of the implant. An increase in 1mm width helps in increasing the functional surface area by about 33 %( 55).

Implant length is another factor because increase in length helps in bicortical stabilization. Maximum stress generated by the lateral loading on the implant can be dissipated by the implants in the range of 10-15mm (56). If the patient is having softer bone then greater length and width of the implants may be required in order to increase the likelihood of Osseo integration. In order to facilitate implant placement with increased length and width, sometimes procedures like sinus grafting and nerve repositioning may be required. However longer implants are necessarily not always better and their use have to be judicially restricted depending upon variation in different cases (57).

Implants with crestal module design prevent bacterial ingress, provides initial stability and also helps in increasing the surface area of the implant. Implant with crestal module angled at less than 20 degrees helps in increasing the implant bone contact area and also provides for beneficial compressive load (58). Apical design of the implant provides with anti-rotational feature and also helps in resisting torsional load. Anti-rotational feature can be added by adding a hole or vent in the apical design of the implant which allows for bone to grow. Flat sided groove placed on the side of the implant helps the implant to resist compression load (59).

Surface coating of the implant with Titanium plasma spray or hydroxyapatite coating has been also advocated to provide increased surface area, roughness for initial stability and stronger implant bone interface (60). Disadvantages of surface coatings includes flaking or scaling upon insertion, plaque retention, increase chances of bacterial infections and increased cost.

**Implant protected Occlusal scheme:-**

Implant protected occlusion scheme was given by Misch in 1993 which advocates transfer of occlusal load within physiologic limit (61). Implant protected occlusion should have no premature contacts or interferences by providing the timing of occlusal contact.

**Timing of the occlusal contact: -** Implant has no periodontal ligament so concerns arise about potential of non- mobile implant to bear total load of the prosthesis when joined to the mobile natural teeth. When exposed to sudden initial movement the tooth moves around 8-28µm in vertical direction under 3 to 5 pounds of force. Secondary tooth movement depends upon property of the surrounding bone. Implant however no sudden initial movement has and may move 3 to 5 µm after bone causes it to move.

**Influence of Surface area: -** An important parameter in Implant protected occlusion is adequate surface area to sustain the load transmitted to implant prosthesis. Following are the methods suggested to influence the surface area of the implants.

1. When implants of decreased surface area are subjected to angled or increased loads, additional implants can be placed to decrease magnified stress and strain.
2. By increasing the number of implants the load can be further distributed.
3. Splinting the implant crowns can further increase the surface area and help in distributing the load.
4. When forces of higher magnitude and duration are anticipated then ridge augmentation is advised.
5. Prosthesis type can be modified from fixed prosthesis to a removable prosthesis to reduce the load.
6. Wider root form Implants could be chosen over narrower implants to allow for load dissipation.

**Mutually protected articulation: -** Anterior guidance of the implant prosthesis with anterior implants should be as narrow as possible. The steeper the incisal guidance greater is the force on the anterior implants. It has been shown that with every 10 degree change in the angle of disclusion there is 30% difference in the load.

 **Implant body orientation and Influence of load distribution:-**

When the direction of force changes to a more angled load stress, magnitude of force increases three times or more. In addition rather than compressive force which can be more easily sustained by an implant the tensile and shear forces are increased in angled load(64).

**Bone mechanics and force direction:-**

Cortical bone of human beings is reported to be strongest in compression, about 30% weaker in tension and about 65% weaker in shear. Implant protected occlusion attempts to eliminate or reduce all shear loads to implant-bone interface (65). As shear forces are increased with an angled load, attempt should be made to reduce the negative effects of angled load (66).

**Crown cusp angle:-**

Natural teeth have about 30 degrees of cusp angulation and the cusp angles modify the direction of forces to the implant resulting in angled load to the crestal bone. Occlusal contact on the implant crown is ideally is a flat surface created by increasing the width of the central groove to about 2-3 mm and recontour the opposing cusp(68).

**Crown height and Implant protected occlusion:-**

Crown height with the lateral load may act as a vertical cantilever and magnifier of stress at implant bone interface (69). Whatever load is applied to the occlusal table it gets magnified by crown height for example a 12 degree angled load of 100 N on implant crown results in 21 N lateral loads and if crown height is 15 mm and final load to crestal bone 315 N moment of force(70).

**Occlusal contact positons:-**

 Although the number of occlusal contacts in a occlusal scheme varies but according to theory on occlusion there should be a tripod contact on each stamp cusp therefore in each marginal ridge and in central fossa(72). Posterior implant must always be placed under the central fossa of the opposing crown because a buccal cusp contact is an offset and produces cantilever load which can cause failure of the prosthesis. Ideal occlusal contact is that which transmits occlusal load along the axial length of the implant.

 **Implant crown contour:-**

Once teeth are lost maxillary ridge resorbs in a medial direction as it evolves slowly to become narrower in width. The posterior mandible also resorbs lingually and as a result the endosteal implants are more lingual then their natural tooth predecessors. As the ridge shifts lingually with resorption of the implant body is not under the buccal cusp tips but near the central fossa or even more lingual under the lingual cusp of the natural tooth.

The occlusal width of a posterior mandibular implant crown is related to the position of the implant body. Lingual contour should mimic the natural tooth while the central fossa should be widened by about 2-3 mm to receive primary occlusal contact. Buccal cusp is reduced in width to decrease the offset load on the crown.

Implants in esthetic zone replacing the canine and premolar are placed more facial so that the crown emergence may appear more natural. Palatal contours of maxillary implant crowns are reduced for improved hygiene and less offset load to the implants.

**OCCLUSAL MATERALS:-**

Occlusal surface materials affect the transmission of forces and maintenance of occlusal contacts. Occlusal material fracture is one of the most common complications in implant. Various materials like porcelain, acrylic resin, metal and composite are used as occlusal materials for implants. While loading the occlusal material over the implant the following protocol is to be followed. In the initial step there should be no occlusal material placed over implant with no occlusal contact. In the intermediate step there provisional restoration in the form of acrylic material which has low impact force should be placed in out of occlusal contact. A final restoration can be given in occlusion with the opposing teeth made up of metal or porcelain.

**OCCLUSAL RISK FACTORS:-**

Factors like Bruxism or Parafunction are of greatest threat to the implant supported restorations. Lateral occlusal contact on the implant supported prosthesis along with any other occlusal prematurity can cause failure of the prosthesis. Whenever a complete implant supported rehabilitation is done in a patient who is a known case of bruxism, then it is recommended to use a night guard by the patient. It is also of absolute necessity that metal discluding guidance to be built in to the implant supported prosthesis in case of a bruxism patient.

**CONCLUSION:-**

Biomechanics is one of the most important considerations affecting the framework design for implant bone prosthesis. It must be analyzed during diagnosis and treatment planning. It may influence the decision-making process, which ultimately reflects on the longevity of the implant-supported prosthesis.

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